NEW APPROACH TO TOTAL DOSE SPECIFICATION FOR SPACECRAFT ELECTRONICS

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Supported by the NASA Living With a Star Space Environment Testbed Program

To be presented by Mike Xapsos at the 2017 Applied Space Environment Conference (ASEC), Huntsville, Alabama, May 15-19, 2017

Acronyms

- AE9 – Aerospace electron model-9
- AP9 – Aerospace proton model-9
- CDF – cumulative distribution function
- COTS - commercial off the shelf
- DDD – displacement damage dose
- ESP – Emission of Solar Protons (model)
- FP – failure probability
- GEO – geostationary Earth orbit
- HST – Hubble Space Telescope
- JUNO – JUpiter Near-polar Orbiter
- LEO – low Earth orbit
- MMS – Magnetospheric MultiScale
- NOVICE – Numerical Optimizations, Visualizations and Integrations on Computer Aided Design (CAD)/Constructive Solid Geometry (CSG) Edifices
- PDF – probability density function
- RDM – radiation design margin
- TID – total ionizing dose

Outline

- **Background**
- **Device Failure Distributions in Total Dose**
- **Total Dose Distributions in Space**
- **Device Failure Probability during a Mission**
- **Conclusions**
  - **Failure Probability (P_{fail}) vs. Radiation Design Margin (RDM)**

Space Environment Model Use in Spacecraft Life Cycle

Mission Concept

Mission Planning

Design

Space Climate
Minimize Risk

Launch

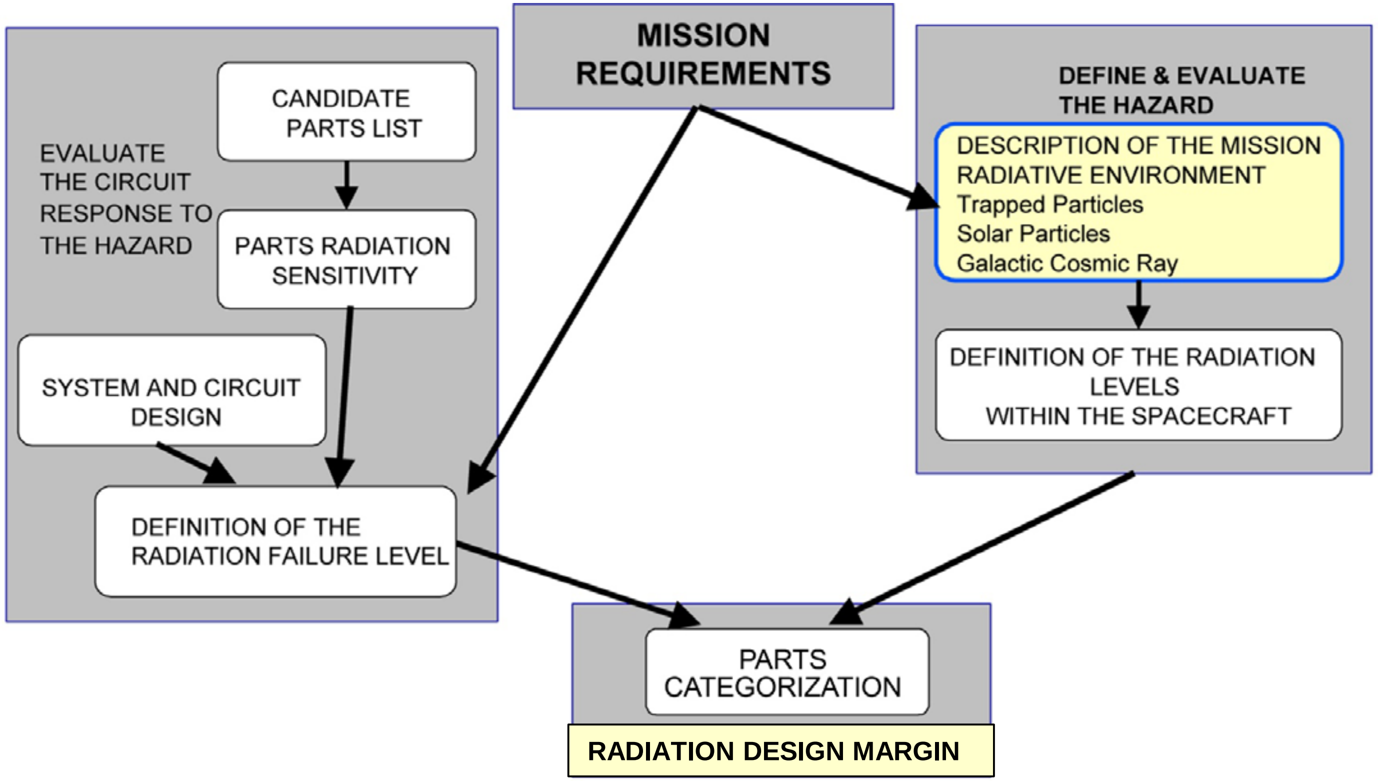
Operations

Space Weather
Manage Residual Risk

Anomaly Resolution → **Both**

Radiation Hardness Assurance Overview

- **Starting with mission requirements, methodology consists of 2 branches of analyses that lead to parts categorization**
  - **Parts analysis**
  - **Environment analysis**



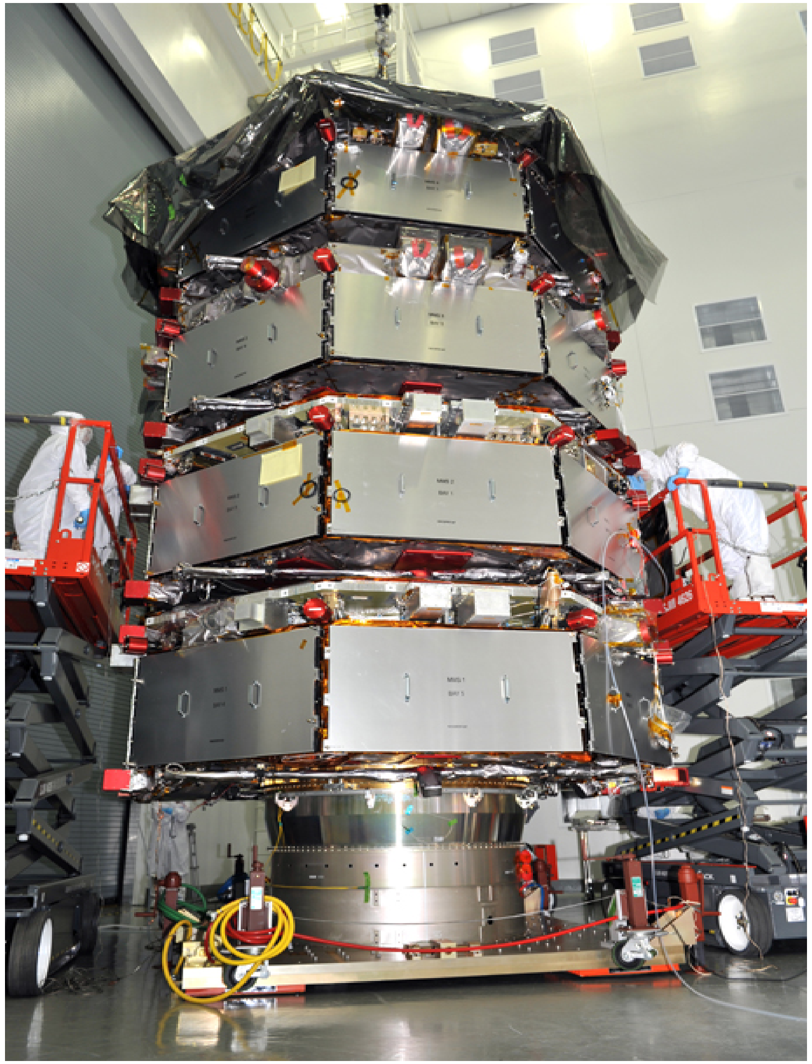
Radiation Hardness Assurance Overview

- **Parts are categorized for flight acceptability and possible radiation lot acceptance testing by Radiation Design Margin (RDM).**
- **RDM = R_{mf} / R_{spec}**
- **R_{mf} is mean failure level of part**
  - **Part failure levels can vary substantially from the mean, especially COTS**
- **R_{spec} is total dose level of space environment**
  - **Environment is dynamic and must be predicted years in advance**
  - **Some environment models are deterministic; some are probabilistic**
  - **Results in inconsistent and arbitrary approach**
- **RDM used as a "catch-all" to cover all uncertainties in environment and device variations**
- **Propose modified approach**
  - **Use device failure probability during a mission instead of RDM**

Devices Tested

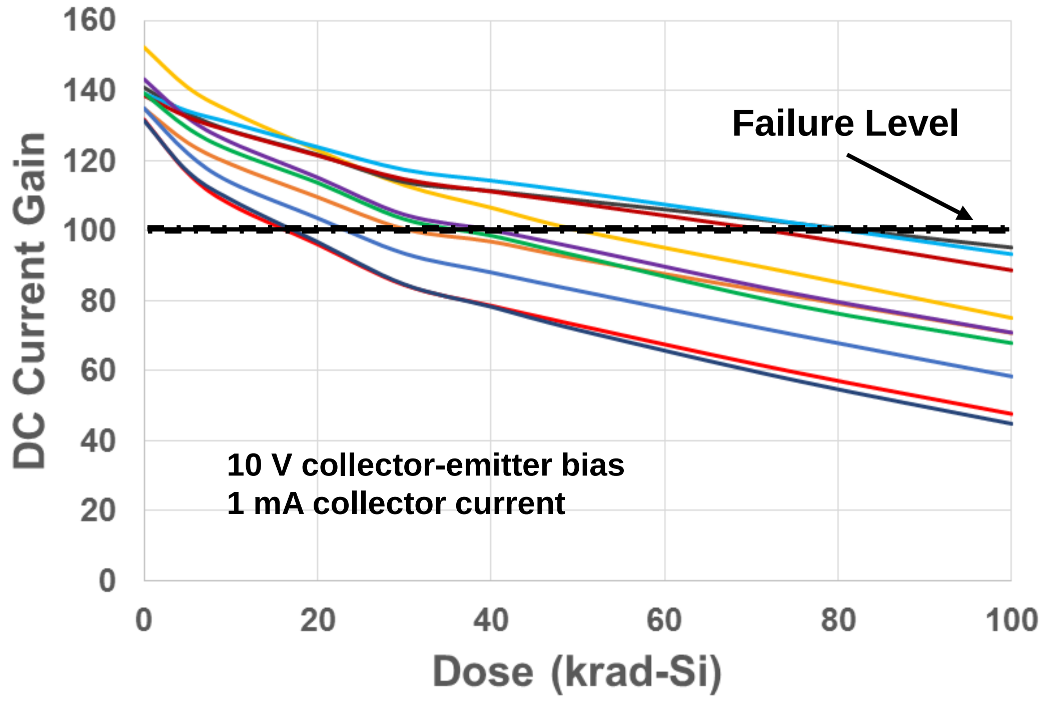
- **Solid State Devices, Inc. SFT2907A bipolar transistors**
  - **Used for high speed, low power applications**
  - **10 devices TID tested for MMS project at NASA/GSFC gamma ray facility to 100 krad(Si)**
- **Amptek, Inc. HV801 optocouplers**
  - **GaAlAs parts manufactured in liquid phase epitaxially grown process**
  - **6 devices DDD tested for JUNO project at UC Davis Cyclotron with 50 MeV protons**

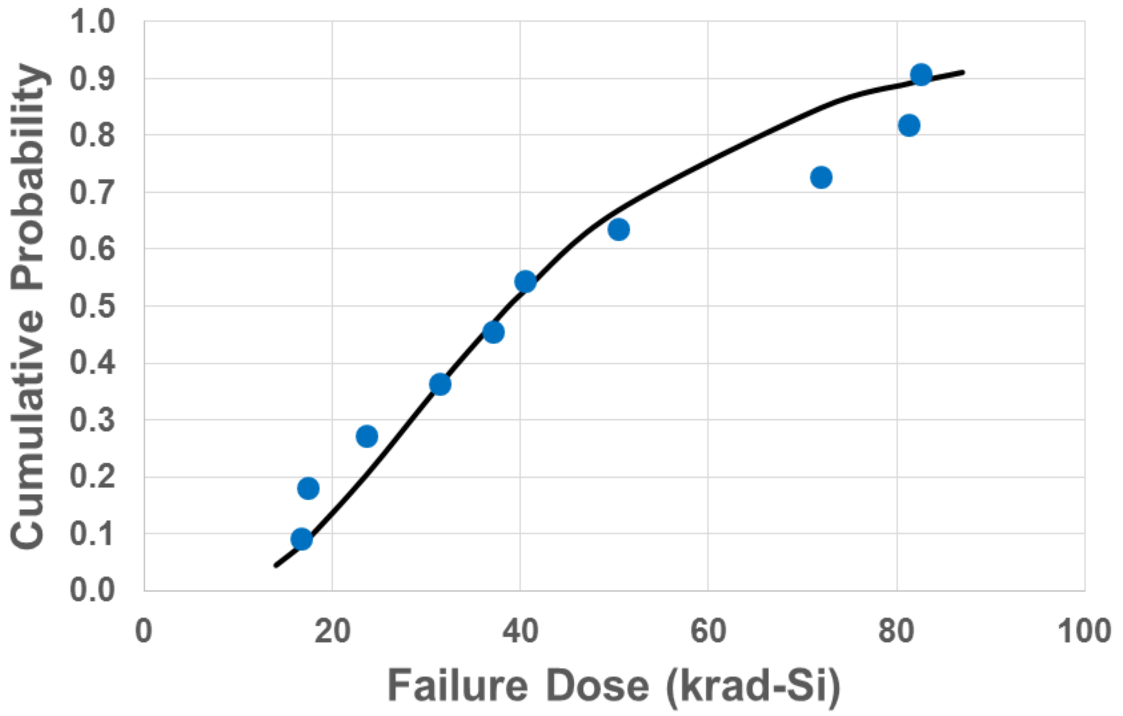
4 stacked MMS spacecraft



Credit: http://mms.gsfc.nasa.gov

Device Failure Distribution
SFT2907A Bipolar Transistors



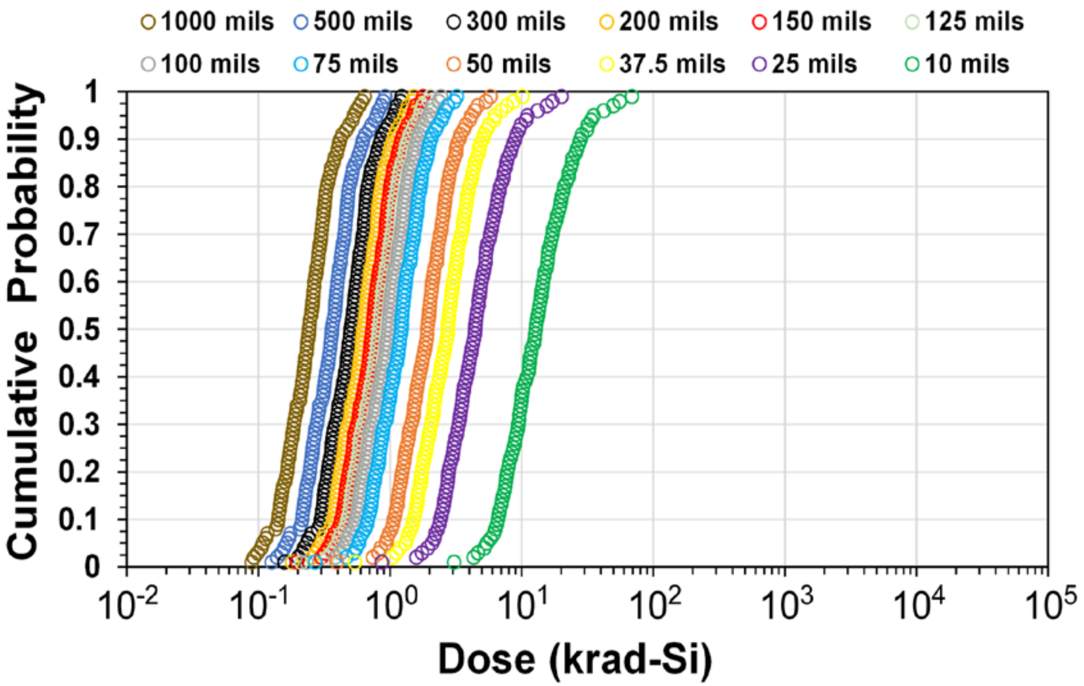


Total Dose Probability Distribution Calculations

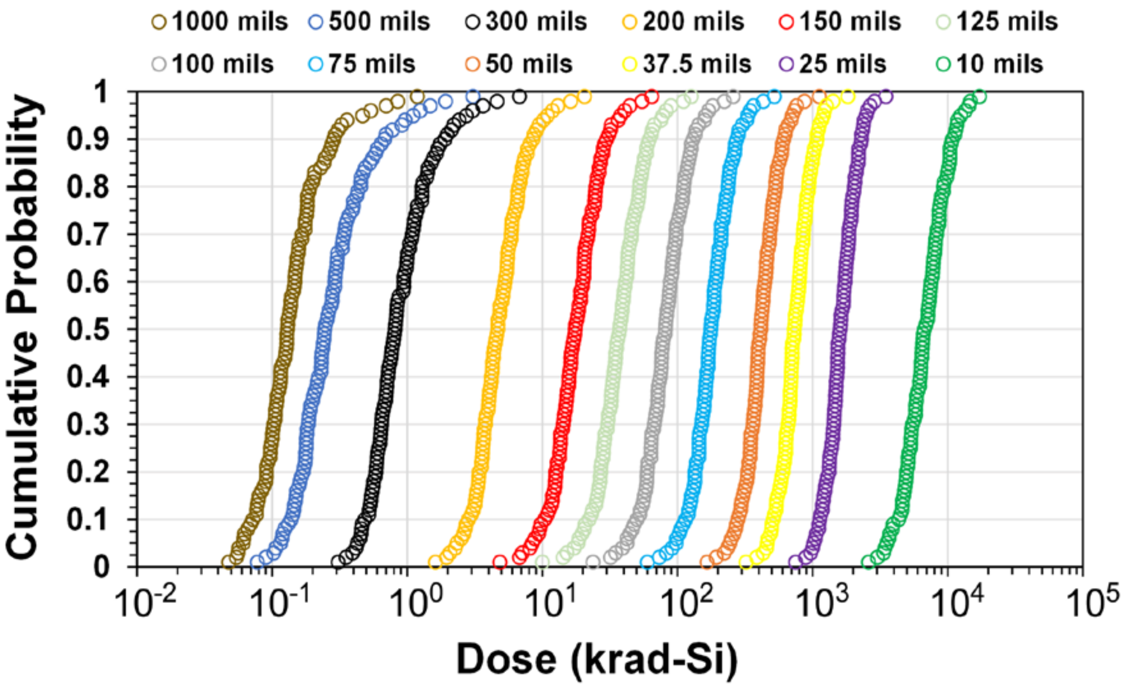
- **TID and DDD probability distributions were calculated for each orbit and mission duration for confidence levels ranging from 1 to 99%**
  - **AP9/AE9 Monte Carlo code used to simulate 99 histories for each case**
  - **ESP solar proton calculations done for 1 to 99% confidence levels**
  - **All energy spectra were transported through shielding levels from 10 to 1000 mils Al using NOVICE code and converted to doses**
  - **TID and DDD for each radiation were separately ranked for confidence levels ranging from 1 to 99% and summed for same confidence and shielding levels**

TID Probability Distributions for 1 Year
10 – 1000 mils Aluminum

Low Inclination LEO



GEO

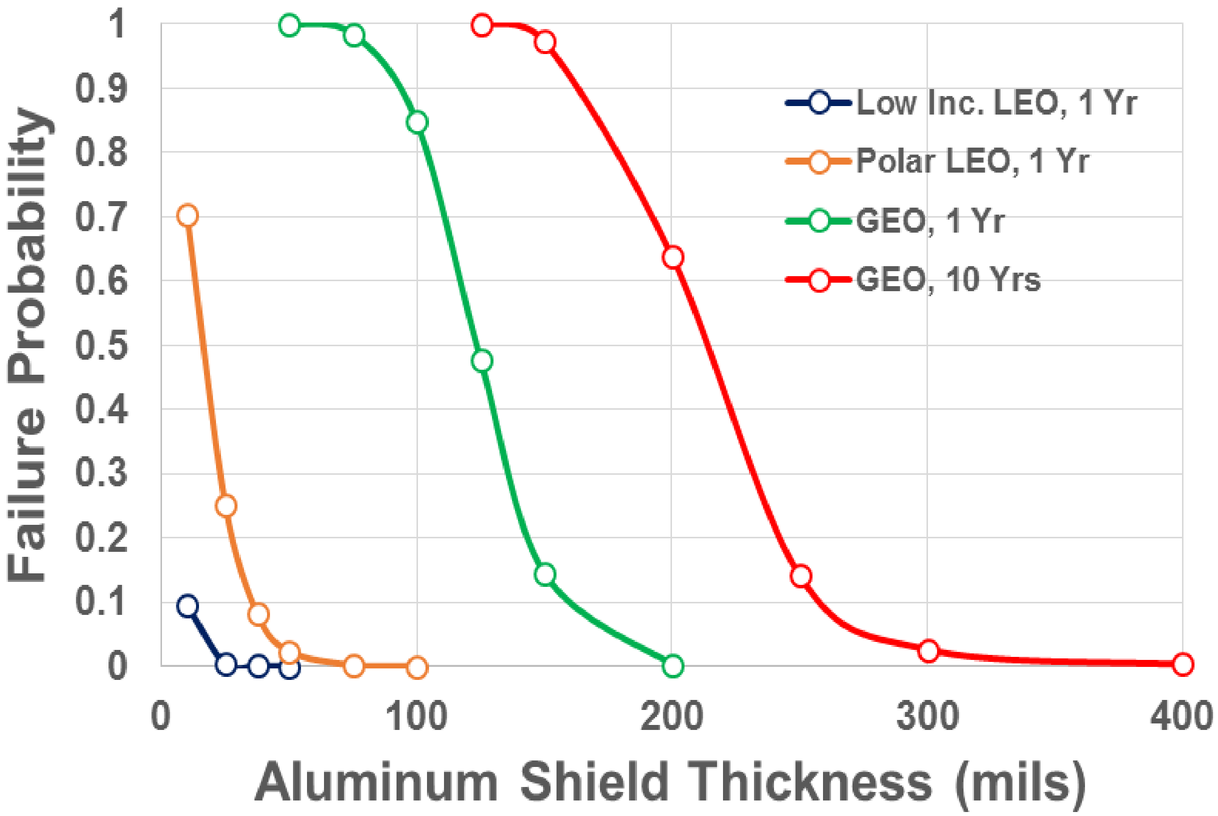


Failure Probabilities
SFT2907A Bipolar Transistor

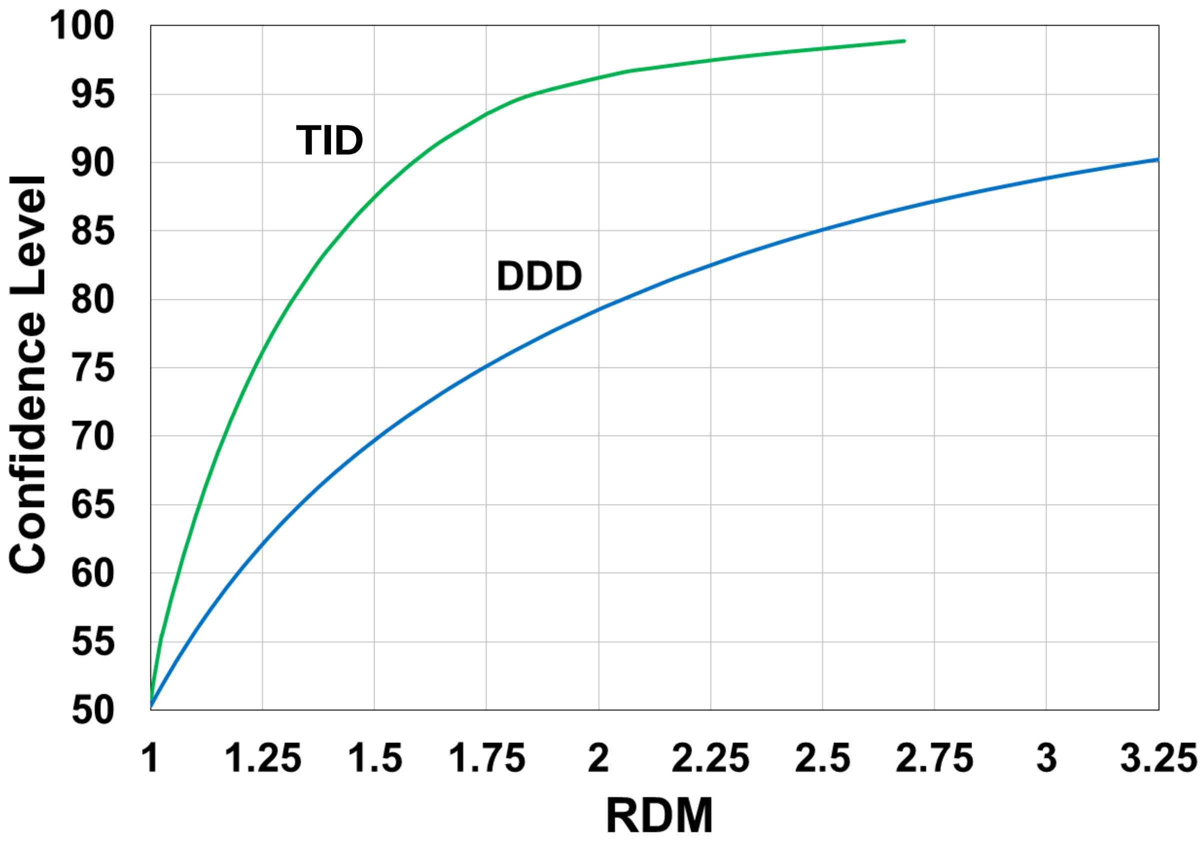
$$P_{fail} = \int [1 - H(x)] \cdot g(x)dx$$

H(x) = CDF for environment dose
g(x) = PDF for device failure

Failure probability (P_{fail}) is the probability of a total dose failure during a mission



Confidence Level vs. RDM for 10 years in GEO 200 mils Al shield



Conclusions

- **An approach to total dose radiation hardness assurance was developed that includes variability of the space radiation environment.**
- **Examples showed radiation environment variability is at least as significant as variability of total dose failures in devices measured in the laboratory.**
  - **New approach is more complete**
  - **Uses consistent evaluation of each radiation in the space environment through use of confidence levels**
- **Advantages of using P_{fail} instead of RDM are:**
  - **P_{fail} is an objectively determined parameter because complete probability distributions are used to calculate it**
  - **Better characterization of device radiation performance**
  - **Allows direct comparison of the total dose threats for different devices and missions, regardless of whether degradation is due to TID or DDD**
  - **More amenable to circuit, system and spacecraft reliability analysis**